PERFORMANCE OF THE ADVANCE WARNING FOR END OF GREEN SYSTEM (AWEGS) FOR HIGH SPEED SIGNALIZED INTERSECTIONS

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ABSTRACT

One major difficulty with traffic signal operation on high-speed approaches is the dilemma faced by approaching motorists when the downstream signal turns yellow. Should the motorists stop or proceed through the intersection? Crashes that may occur at these intersections result in high property damage and personal injury.

Texas Transportation Institute (TTI) has developed a new system named Advanced Warning for End-of-Green System (AWEGS) for applications to high-speed signalized intersections. Typically, the dilemma zone detection strategy is based on a certain approach speed (typically 85th percentile). AWEGS provides protection for a majority of motorists that are not covered by the dilemma zone treatment. AWEGS provides advance warning to motorists using roadside mounted signs. These signs (BE PREPARED TO STOP WHEN FLASHING) would flash the beacons about 5 - 6 seconds before the onset of yellow for the high speed approaches. Similar systems have been implemented in Canada and in a few states in the US using trailing green approach resulting in loss of dilemma zone protection every cycle. AWEGS on the other hand functions almost completely independent of the traffic signal controller and hence the signal controller would continue to provide the dilemma zone protection that it was designed for.

The system was implemented at four sites in Waco, Brenham, College Station, and Lubbock in Texas. Results of AWEGS implementation illustrated an improvement in traffic operations. AWEGS consistently enhanced the dilemma zone protection at the intersections and reduced the red-light running by an average of 40 to 45%.

INTRODUCTION

Many signalized intersections are being installed by TxDOT have approaches with speeds of 50 mph or higher. Many locations have approach speeds nearing 70 mph. One of the major difficulties with traffic signals on high-speed approaches is the "dilemma" a motorist faces when the signal turns yellow. Webster defines a dilemma as: "*a.* a choice, or situation involving choice, between equally unsatisfactory alternatives, or *b.,* a difficult or persistent problem (*1*). This is clearly a useful characterization for the forthcoming decision facing some motorists at the loss of their green signal.

At the start of the yellow change interval, all approaching motorists are faced with a decision to proceed through the intersection or bring their vehicle to a safe stop. The decision to stop is easy to make when the vehicle is far from the intersection at the onset of yellow change. Similarly, the decision to continue to travel through the intersection is easy to make when the vehicle is close to the intersection. However, between these two opposite decision points exists a zone where the decision to stop or proceed is not as easy, even if the signal is timed according to national traffic engineering guidelines (*2*). Increasing speeds and volumes increase the likelihood (frequency) and severity of potential crashes that may occur at these signalized intersections thereby significantly increasing the toll of property damage and personal injury. Dilemma zone becomes a more critical issue in the case of trucks. Trucks have different braking characteristics and take longer time and distance to stop. Failure by the trucks to stop safely has the potential to cause severe accidents at the intersections.

With the objective to improve safety on highways in mind, Texas Department of Transportation (TxDOT) sponsored a project to develop methods to provide an early warning of the end of green on the high-speed approaches. These methods would reduce the number of crashes, reduce pavement damage due to sudden braking, and reduce or eliminate driver's dilemma approaching a high-speed signalized intersection resulting in reduced red-light running.

The objective of this paper is to briefly describe the functionality of AWEGS, AWEGS performance, and reduction in red-light-running. This paper will emphasize on AWEGS performance.

OTHER METHODS

The installation of Advance Warning Flashers (AWF) devices can be traced as far back as 1968 in Alberta, Canada. Throughout the United States and Canada, AWF installations have been documented to take on a number of different designs and practices. A study (*3*) identified ten different text messages that were used by ten different state agencies and five cities. The ten different text messages include the following:

- Stop Ahead
- Stop Ahead When Flashing
- Red Signal Ahead
- Signal Ahead Prepare to Stop When Flashing
- Prepare to Stop When Flashing
- Prepare To Stop
- Signal Ahead sign supplemented with flashers
- When Flashing Stop Ahead
- Be Prepared to Stop When Flashing
- Red Signal Ahead When Flashing

The results of this analysis indicated that the most widely used message was “Prepare To Stop When Flashing”, which was used in six different configurations by five different states and one city. Of the 15 agencies that used the devices contained in this subcategory, three states and one city used more than one device to warn of signal changes.

A summary of design and installation of AWF in the four western provinces of Canada (British Columbia, Alberta, Saskatchewan and Manitoba) indicated that such warning devices has been put into practice through the past 30 years (*4*). These provinces have also developed specific and detailed warrants for installing these warning devices. Warrants for the City of Calgary, Alberta and the province of British Columbia are detailed next.

City of Calgary, Alberta (*4*)

- At all signalized intersections having a posted speed limit of 100 km/h;
- At the first signal into the city on routes where the posted speed limit is in excess of 70 km/h;
- On roadways having a speed limit in excess of 70 km/h where an accident hazard exists that is correctable through the use of advance warning signals; or
- On roadways where horizontal or vertical alignment causes restricted visibility of the approaching intersection.

British Columbia (*5*)

- The posted speed limit on the roadway is 70 km/h or greater;
- The view of the traffic signals is obstructed because of vertical or horizontal alignment (regardless of the speed limit) so that a safe stopping distance is not available;
- There is a grade in the approach to the intersection that requires more than the normal braking effort; or
- Drivers are exposed to many kilometers of high-speed driving (regardless of posted speed limit) and encounter the first traffic signal in a developed community.

The operating strategies used by these AWF systems vary from place to place. In some locations, the signal controller is operating in a fixed time fashion. The AWF is activated a few seconds before the end of green. In many other cases, the traffic signal controller is operating in a fully actuated mode. The AWF is activated a few seconds before the end of green. This is accomplished by a variety of means. One of the ways of accomplishing this procedure is by the use of *trailing overlaps*. Trailing overlaps are fixed in duration and extend the display of a phase after the termination of the phase. When these phases gap out or max out, the Trailing Overlap is initiated and the arterial display continues to show green. As the trailing overlap is initiated, the AWF starts flashing. The AWF will start flashing 4-7 seconds before the onset of yellow depending on the intersection conditions.

Limitations of Current Practices

There are limitations of the currently operating systems. Fixed time traffic signals are not very efficient. They do not react to cyclic variations in the traffic demand. Using trailing overlaps on the other hand addresses the limitation of fixed time operations. However, the system introduces a trailing overlap of a fixed interval at the end of the arterial phase every time, which MAY cause some dilemma zone problems. High-speed approaches on isolated traffic signals have dilemma zone detectors, which monitor traffic conditions and terminate the phase safely when there are adequate gaps in the traffic stream. However by having an interval of fixed duration at the end of the high speed phase for every cycle, the AWF system eliminates the dilemma zone protection provided at the intersection. To overcome this limitation, the Texas Transportation Institute (TTI) developed a system that provides advance warning about the end of green while maintaining the dilemma zone protection being provided by the traffic signal.

ADVANCE WARNING OF END OF GREEN SYSTEM

The objective of this project was to develop an Advance Warning End of Green System (AWEGS) and operating methodology to provide advance warning about the end of green to the motorists on the high-speed approaches to signalized intersections. This device should consistently reduce or eliminate the dilemma faced by a motorist when the signal changes from green to yellow and would not result in unsafe operating conditions due to any failure of the AWF.

Implementation

The AWEGS has been installed at three locations as part of the research project in Texas. These installations were evaluated for reduction in red-light-running. The first site is at the intersection of SH 6 and FM 185 near Waco, and is a two-lane highway with approach speeds of over 55 mph. The second and third sites are at the intersection of US 290 and FM 577 in Brenham, and at the intersection of FM 2818 and George Bush Drive in College Station and were four-lane highways with approach speeds of over 60 mph. These sites represent the majority of the high-speed signalized intersections. Apart from these installations, AWEGS was installed at the intersection of US 84 and CR 1540 near Lubbock where red-light-running evaluation was not performed. This paper will present the performance evaluation of the AWEGS deployments in Waco and Brenham. The College Station and Lubbock sites have similar characteristics as the Brenham sites and will not be discussed here. All AWEGS sites are isolated and operate fully actuated. Each of the sites was different from each other and had unique characteristics to calibrate the algorithm parameters as well as the traffic signal controller settings. Algorithm parameters to be calibrated were affected by speed profiles, approach grade (affecting the deceleration rates), signal visibility, and turning movements. Controller settings to be calibrated were affected by detector location and turning characteristics.

AWEGS Layout

The AWEGS system is composed of advance detectors placed upstream of the dilemma zone detectors, an Advance Warning Flasher, existing dilemma zone detectors for the intersection, and the AWEGS system running on a PC in the cabinet beside the signal controller cabinet. FIGURE 1 illustrates the layout of the AWEGS system in Waco on a SH 6 approach. For clarity purposes only one approach is shown. The other approach has a similar configuration. The Brenham layout has similar configuration except that a pair of advance detectors were installed in each of the two approach lanes and they are located further away from the intersection.

FIGURE 1 shows two advance detectors placed at a distance 865 feet from the stop bar. These two detectors are spaced 30 feet apart from trailing edge to trailing edge. These advance detectors provide the first information about the vehicle arrivals on the high-speed approaches to the AWEGS algorithm. These advance detectors are square with six feet to a side with 24 feet clear space between the two advance detectors. While the location of the advance detectors can be varied slightly to account for local conditions, the spacing of 24 feet between the advance detectors is a must (*6*). A spacing of 24 clear feet between the detectors enables the algorithm to detect trucks from non-trucks in a very simple manner without using a classifier.

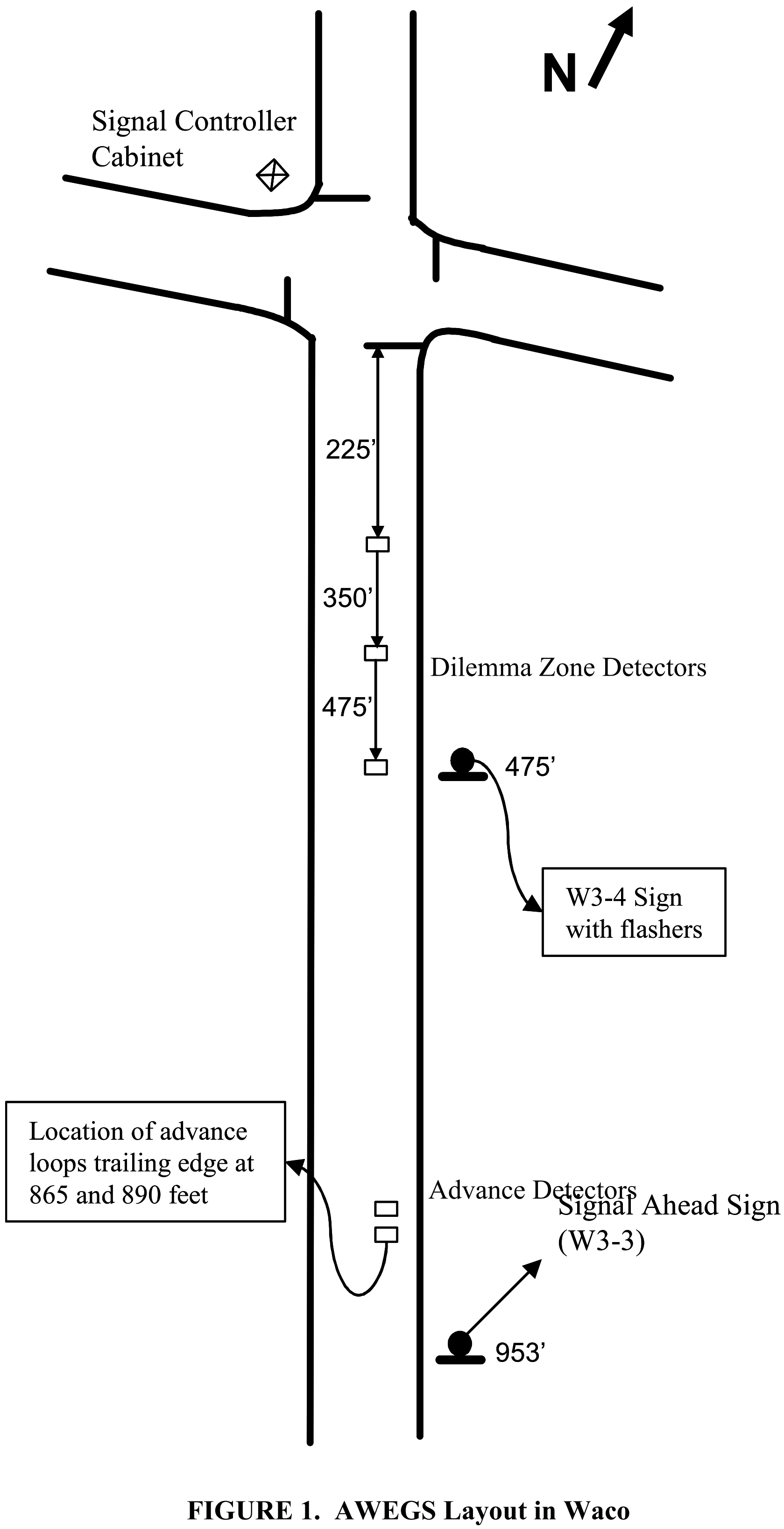

FIGURE 1. AWEGS Layout in Waco

AWEGS Signs

TTI researchers in coordination with TxDOT engineers designed the warning devices that will warn the motorists approaching the intersection. These warning devices conform to the W3-4 device in the Millennium Edition of the Manual of Uniform Traffic Control Devices (MUTCD) (*7*) and an example of the sign used in Waco is illustrated in FIGURE 2. The main sign is a square with a dimension of 48 inches to a side. The WHEN FLASHING plaque is 36" X 24" in dimensions. The beacons are LED beacons and are 12" in diameter. Their placement with respect to the roadway conforms to the placement of warning devices in the MUTCD.

FIGURE 2. Layout of the AWEGS Sign

AWEGS Methodology

The primary objective is to operate AWEGS without influencing the traffic signal controller operation. This will ensure that the intersection is operating in a fully actuated mode all the time and the integrity of the intersection dilemma zone treatment is maintained. Hence, AWEGS functionality is to enhance the existing dilemma zone treatment and not replace it. The challenge then for AWEGS is to predict the operation of a fully actuated traffic signal controller.

AWEGS operation can be categorized into two tasks; forecasting and monitoring. The algorithm forecasts the gap out of the high-speed approaches using the advance detector actuations and calculating the travel time to the dilemma zone detectors. The travel time to the dilemma zone detectors is calculated by using the advance detectors as a speed trap and assuming a constant speed from the advance detectors to the dilemma zone detectors. Surveillance of the gap out timers in the controller is continuously performed by algorithm to prevent any unexpected gap outs. Numerous strategies are employed during the calibration to minimize such occurrences by judiciously applying delays to the detectors in the controller. These delays are usually about two to four seconds and will not have any impact on the efficiency of the signal operations. This enables AWEGS to be aware of the detection before the controller does. AWEGS then activates the flashers on the W3-4 signs when necessary. This can result in the beacons starting to flash at the onset of yellow for cases when there are no vehicles in the dilemma zone to the beacons starting to flash about 4-5 seconds before the onset of yellow. AWEGS in rare cases also placed a hold that varies from vehicle to vehicle to enable a vehicle in a dilemma zone to get onto the TxDOT dilemma zone detectors. Duration of hold is variable. It depends on the speed of the vehicle which determines the dilemma zone for that particular vehicle and the distance of the vehicle from the TxDOT dilemma zone detectors when a conflicting call is received by the controller. Finally, AWEGS also monitors the gap out timer for the dilemma zone detectors and the max-out timers to prevent unexpected gap outs of the high speed approaches (within 0.2 seconds).

As mentioned earlier, objective of AWEGS is to enhance TxDOT's dilemma zone detection system. TABLE 1 illustrates the detector layout used by TxDOT. The challenge for AWEGS is to predict the behavior of the controller and minimize placing a phase hold. Using a phase hold has the potential to introduce vehicles into the dilemma zone at the onset of yellow. AWEGS system had to rely upon very accurate knowledge of the detector placement, existing speed profiles, and signal controller software to be able to reliably predict the gap out of high-speed signal phases. However, to account for the stochastic nature of traffic behavior, TTI researchers did develop a phase hold option in cases where, the signal controller is gapping out unexpectedly. Studies have indicated that such a scenario will happen for fewer than 5% of the phase terminations.

TABLE 1. TxDOT Dilemma Zone Detector Layout

Approach Speed, mph	Distance from Head of Detector to Stopline at Intersection, feet			Stopline Area Detector [a]	Passage Gap, seconds
	CDA[b] 1	CDA 2	CDA 3		
45	330	210	---	6′ x 40′	2.0
50	350	220	---	6′ x 40′	2.0
55	415	320	225	6′ x 40′	1.2
60	475	375	275	6′ x 40′	1.4
65	540	430	320	6′ x 40′	1.2
70	600	475	350	6′ x 40′	1.2

[a] Presence on red; then delayed (no) call on green following first gap-out.
[b] Dilemma Zone Detectors with CDA 1 being the furthest and CDA 3 being the nearest to the stop bar.

AWEGS is composed of a field hardened PC, communicating with the traffic signal controller and placing commands to the AWEGS sign through a custom built flasher panel. The various components and the methodology used by AWEGS are illustrated in FIGURE 3. Actuations from vehicles detected by the advance detectors on the high-speed approach are monitored by AWEGS using a loop amplifier. AWEGS is also monitoring the phase status as well as intersection detectors status. Intersection detectors include the stop bar detectors at the intersection as well as the dilemma zone detectors on the high-speed approaches. The basic premise of AWEGS is to use these inputs to predict the gap out or max-out of the main street phases. When AWEGS predicts that the main street phases will gap out, the system will send a signal to the flasher panel to activate the beacons.

FIGURE 3 illustrates the inputs in the signal controller being monitored using the BIU terminals in a TS-2 cabinet. Similarly phase holds are also placed through the BIU terminals whenever necessary. AWEGS is able to detect unexpected gap outs by monitoring the detections on conflicting phases, detections on the dilemma zone detectors, as well as having knowledge of the passage times programmed in the signal controller. In order to prevent any malfunction of the phase hold function, researchers introduced a timer relay to ensure that the phase hold does not exceed user specified duration. Phase maximum times in the controller are also programmed in AWEGS to provide adequate warning when ever a main street phase is about to max out. The ring structure in use at the intersection is also programmed in AWEGS. This provides safe operations under phasing sequences like lead-lag operations.

FIGURE 3 also illustrates the flasher panel operation. Flasher panel receives a signal from AWEGS to activate the beacons. However, to ensure that the system also operates safely if AWEGS malfunctions, the flasher panel monitors the load switch status and starts flashing the beacons at the onset of yellow for the high-speed approach phases. Operation of such a back up system is consistent with the message on the AWEGS sign.

AWEGS was developed and extensively tested in the TransLink® laboratory at TTI using real equipment. This equipment included connecting AWEGS running on a PC to an actual signal controller cabinet. The prototype flasher panel was installed and detectors hooked up for the advance detectors as well as intersection detectors. The cabinet was connected to signal indications as well as flashing beacons. Individual components were tested extensively and numerous scenarios were simulated to test the algorithm. Testing included satisfactory operations due to a malfunction of the computer, malfunction of the controller, and detection of a preempt signal. During a computer failure, AWEGS monitors signal status and flashes the beacons during the yellow and red indications on the main street. This operation is not inconsistent with the message on the W3-4 sign. During the failure of the traffic signal controller or during the presence of a preempt call, AWEGS immediately starts flashing the beacons for the duration of the condition.

OPERATING PERFORMANCE

The function of AWEGS is to provide an advance warning before the end-of-green to the traffic on the high-speed approaches. The system monitors all the detections at the intersection, detections on the advance detectors on the arterial approaches, and the signal controller status. Based on the detector activity, AWEGS then predicts the termination of green about 5 to 6 seconds in advance for each high-speed approach and activates the beacons.

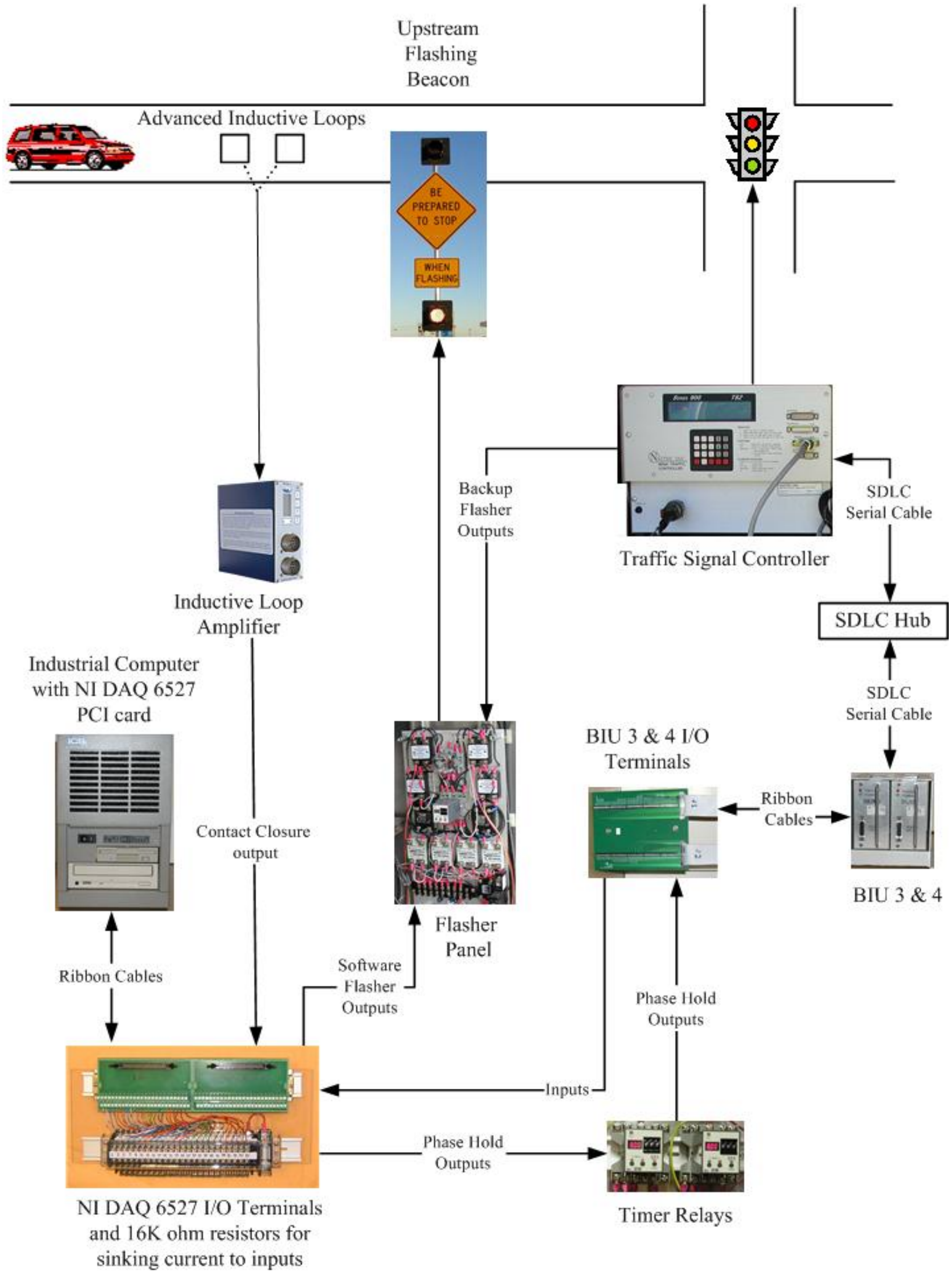

FIGURE 3. Schematic of the methodology of the AWEGS System

AWEGS makes decisions on termination of green based on several assumptions regarding vehicle detection and operation. However, motorists do not always drive in a predictable manner. They sometimes slow down on an approach and sometimes speed up. To overcome this variability of driver behavior, the system monitors the signal controller to provide high-quality prediction. If the prediction is proving to be false, AWEGS has to catch up with the controller operations to warn the vehicle by delaying the termination of green if a vehicle is in the dilemma zone. This is done by placing a phase hold. Sometimes the advance warning is longer than 5 to 6 seconds. This happens when advance detectors detect a vehicle that happens to be at the head of a platoon. If just after the first vehicle is detected, a vehicle is detected on a conflicting phase, and the controller is ready to gap out, the beacons start flashing expecting that the high-speed phase would terminate in a few seconds. However, the arrival of the platoon may extend the high-speed approach for a significantly longer duration resulting in a longer than 5 to 6 seconds advance warning time.

Sometimes no advance warning on the arterial may be provided. This usually will happen because no advance warning is necessary. This may happen when there is a call on a conflicting phase when there are no vehicles on the high-speed approaches (as may happen during off-peak periods). Here, no need exists to provide any advance warning for the high-speed approaches.

Sometimes AWEGS is unable to distinguish a real detection on a detector from a false call. For example, a real detection on a side-street stop bar detector is a vehicle waiting for a green on the side street. A false detection on the same detector is a left-turning vehicle from the arterial traveling over the same detector during an arterial left-turn movement. Using inductive loop detectors, the amplifier in the cabinet is unable to distinguish this detection as being a false call. Hence, AWEGS reacts to this false detection as if it was a true call, and may immediately activate the beacons if conditions are appropriate. However, the system usually soon recognizes the false call and stops flashing the beacons when it is safe to do so. This situation sometimes leads to false calls resulting in false flashing and may result in a large variation in the warning time provided to approaching motorists. This unnecessary flashing can be minimized by providing good intersection geometric design initially and improved directional detection capabilities. However, the AWEGS has been designed to minimize this variation in warning time and ensure that it does not have an adverse impact on approaching motorists.

Phase holds and duration of advance warning are two means of evaluating AWEGS performance. The following sections provide details of these two parameters.

Phase Holds

In order to better understand system performance, three weeks of detailed data were examined from the AWEGS operations in Waco and in Brenham. Researchers analyzed these data to determine the hold patterns, the number of phase terminations, and the pattern of the advance warning being provided on a typical day. TABLE 2 illustrates the statistics observed in Waco and Brenham regarding the number of phase holds and the mean duration of phase holds for one week. The table also illustrates the number of phase ends for each approach. As TABLE 2 illustrates for Waco, the range for the number of phase holds for Phase 2 was from 2 to 9 for an average of 5 and for Phase 6 from 5 to 13 for an average of 9 per day. It is also seen from the table that the average duration of the phase holds are 1.6 seconds and 1.4 seconds for Phase 2 and Phase 6, respectively.

TABLE 2 shows a significant difference between the number of phase holds for Phase 4 and Phase 8 for Brenham. While the phase holds for Phase 4 range from 11 to 21 for an average of 16 per day, they range from 0 to 6 on Phase 8 for an average of 3 per day. Similarly, the number of phase ends ranges from 886 to 922 for Phase 4 for an average of 904, and they range from 468 to 551 for Phase 8 for an average of 517 per day. These results are expected, as there is a significant amount of traffic on Phase 3, which is the arterial left-turn movement opposing Phase 4. Hence, Phase 4 terminates more often than

Phase 8 resulting in more phase holds. It is also seen from the table that the average duration of the phase holds are 2.1 seconds and 1.9 seconds for Phase 4 and Phase 8, respectively.

TABLE 2. Phase Hold and Terminations in Waco and Brenham

Waco								
Day	Phase 2 (Leading Through)				Phase 6 (Leading Through)			
	# of Holds	Mean Hold (Seconds)	Std. Dev	Phase Ends (#)	# of Holds	Mean Hold (Seconds)	Std. Dev	Phase Ends (#)
Sunday	5	1.714	0.828	1033	5	1.207	0.225	1014
Monday	5	1.441	0.245	1052	10	1.88	0.823	1044
Tuesday	9	1.619	0.596	1085	9	1.416	0.674	1092
Wednesday	2	1.507	0.419	1086	13	1.453	0.451	1082
Thursday	5	1.552	0.626	1025	13	1.527	0.652	1124
Friday	2	1.842	0.636	1173	6	1.137	0.125	1162
Average	5	1.6	0.6	1076	9	1.4	0.5	1086
Brenham								
Day	Phase 4 (Lagging Through)				Phase 8 (Leading Through)			
	# of Holds	Mean Hold (Seconds)	Std. Dev	Phase Ends (#)	# of Holds	Mean Hold (Seconds)	Std. Dev	Phase Ends (#)
Sunday	15	1.819	0.627	895	6	2.618	1.359	468
Monday	16	2.005	0.898	904	5	2.238	0.83	527
Tuesday	11	2.478	1.136	907	3	2.303	0.108	551
Thursday	16	2.044	1.073	907	0	0	n/a	503
Friday	21	2.246	0.913	886	1	2.003	0	511
Saturday	15	2.09	0.771	922	1	2.533	0	540
Average	16	2.1	0.9	904	3	1.9	0.4	517

To summarize, in Waco a phase hold of an average of 1.4 to 1.6 seconds is being applied not more than 9 times per day out of about 1,100 phase terminations. In Brenham, a phase hold of an average of 1.9 to 2.1 seconds is being applied not more than 16 times on an approach having over 900 phase terminations. This confirms that AWEGS is not having a significant influence on the fully actuated operations of the traffic signal controller.

Advance Warning

The data collected were also analyzed for the distribution of advance warning being provided to the motorists. Additional information about the number of times no advance warning was provided as well as the number of times AWEGS started flashing for false calls and stopped flashing after realizing the error. For the sake of brevity, results for only one day are provided in TABLE 3. TABLE 3 illustrates the results of the data analysis for Day 1 in both Waco for Phase 2 and Phase 6 approaches and Brenham for Phase 4 and Phase 8 approaches.

TABLE 3 provides information about three parameters regarding the advance warning for each approach. The column Flash at the Onset of Yellow illustrates the number of times AWEGS did not provide any advance warning of the end-of-green, meaning that the beacons started flashing at the onset of yellow. This operation is very efficient and does not necessarily suggest an unfavorable situation. AWEGS does not provide an advance warning when no vehicles are detected on the arterial approaches when a conflicting call is received. Providing a warning under such cases will only delay serving the vehicle on the side street and makes the intersection signal operation less efficient.

TABLE 3. Beacon Flashing Summary for Waco and Brenham for Day 1

	Flash at the onset of Yellow	Flash to Start of Yellow	Flash for false actuations	Flash at the onset of Yellow	Flash to Start of Yellow	Flash for false actuations
Waco	Phase 2 (Leading Through)			Phase 6 (Leading Through)		
Count (#)	19	1009	20	5	1030	26
Min (Secs.)		0.1	0.1		0.3	0.0
Max (Secs.)		27.0	4.9		40.9	6.2
Average (Secs.)		3.7	1.9		4.7	1.9
StDEV		3.4	1.7		4.3	1.8
Brenham	Phase 4 (Lagging Through)			Phase 8 (Leading Through)		
Count (#)	150	744	15	4	460	1
Min (Secs.)		0.0	0.1		0.2	0.7
Max (Secs.)		46.4	4.0		94.8	0.7
Average (Secs.)		4.7	0.8		11.3	0.7
StDEV		3.6	1.0		14.8	n/a

The column Flash to Start of Yellow contains the most critical information. This column states the number of times the advance warning was provided, illustrates the range of the advance warning by detailing the minimum and the maximum advance warning provided, and calculates the mean and standard deviation of the range of advance warning for the particular approach. The third column Flash for False Actuations indicates the number of times AWEGS started flashing the beacons for an unknown false call and then had to stop flashing when the system recognized the false call. This column indicates the number of times AWEGS corrected its actions either due to unexpected driver behavior, false calls, or wrong assumptions.

As can be seen in TABLE 3, in Waco the beacons started flashing at the onset of yellow 19 times for Phase 2 and 5 times for Phase 6. This is an indication of lack of traffic on the main street when a side street phase was called. There was a higher discrepancy in Brenham, where no advance warning was provided 150 times for Phase 4 and 5 times for Phase 8. This was because a number of vehicles from Phase 3 were turning on the red and were actuating a detector in the median which AWEGS was not monitoring. Hence, the Phase 4 was terminating unexpectedly a number of times for these vehicles which were not under AWEGS surveillance. Subsequent to the data collection, AWEGS started monitoring these detectors and the number of these terminations reduced significantly.

It is seen that the average advance warning in Waco was 3.5 to 3.7 seconds. In Brenham the average advance warning was 4.7 seconds for Phase 4 and 11.3 seconds for Phase 8. To get an understanding of the distribution of the advance warning being provided, a frequency distribution of advance warning was plotted. FIGURE 4 and FIGURE 5 illustrate the frequency distribution of the advance warning being provided in Waco and Brenham respectively. Frequency distributions illustrate that a large number of advance warnings were of a duration of about 1 to 2 seconds. This is not a faulty operation of AWEGS. Due to the delays placed on the side street detectors, AWEGS knows about a vehicle presence on the side street before the controllers knows. Under these conditions, if there were no vehicles on the main street, AWEGS starts flashing the beacons immediately and after the detector delay of 1-2 seconds expires, the main street phase gaps out initiating the onset of yellow indication. If these advance warnings were disregarded, the frequency distributions illustrate that the majority of the advance warning were about 5 to 6 seconds in duration which meets the overall system objective.

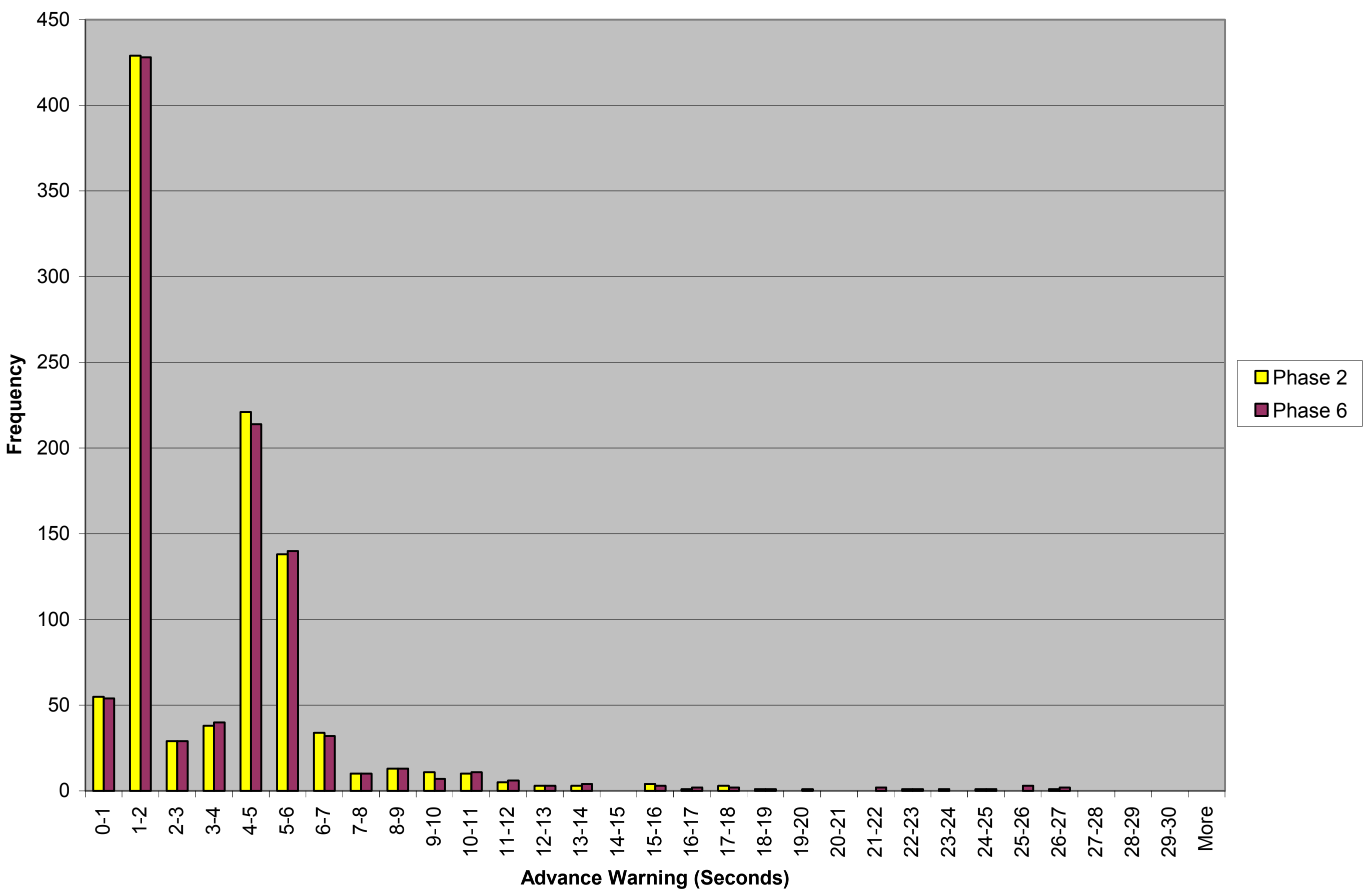

FIGURE 4. Advance Warning Distribution in Waco - Day 1.

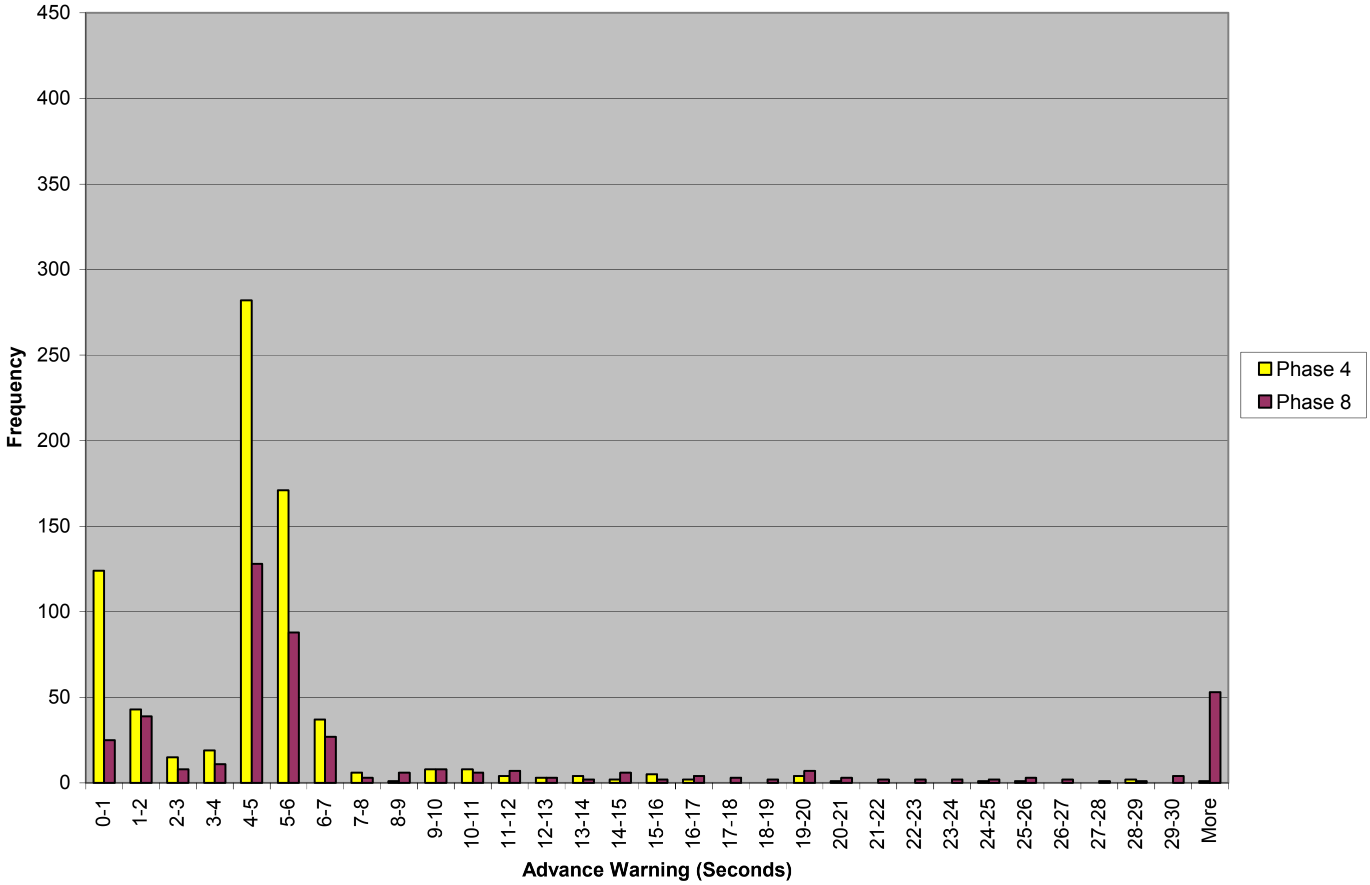

FIGURE 5. Advance Warning Distribution in Brenham - Day 1

REDUCTION IN RED-LIGHT RUNNING

One of the primary objectives of this project is to minimize vehicles present in the dilemma zone at the onset of yellow. A reduction in the number of vehicles in the dilemma zone at the onset of yellow will reduce the number of vehicles running the red light. Red light runners can cause some serious accidents and any reduction in red-light running is a significant benefit. TTI researchers used the reduction in red light running as the primary measure of effectiveness (MOE) to evaluate AWEGS.

To evaluate the number of red-light runners, TxDOT installed a two-camera video detection system at the intersections. This detection system was used to draw loops in the intersection area downstream of the stop bar. AWEGS system is monitoring the phase status from the signal controller. The system assigns a time stamp at the onset of yellow, All-Red, and Red. The system also is monitoring the status of the video detectors used for red-light running evaluation. The system assigns time stamps for the time when the detectors are activated and when they are deactivated. This information gives us the presence time on the detector too. By comparing the signal status information with the video detector status, red-light runners are identified. It should however be noted that this information about red-light running is only used for AWEGS system evaluation and not for enforcement. No individual vehicles are identified. Overall, a 40 to 45 percent reduction in red-light-running was obtained at the two sites. FIGURE 6 illustrates the reduction in red-light-running in Waco and Brenham.

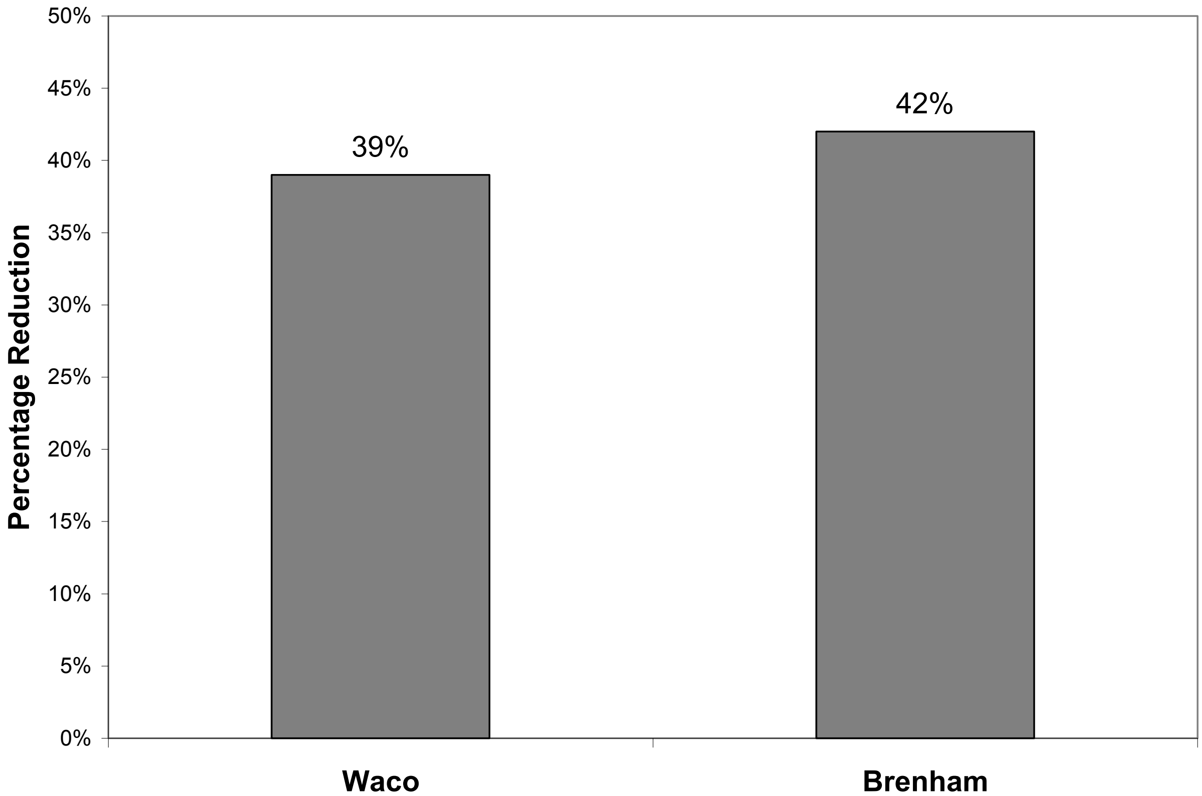

FIGURE 6. Reduction in Red-Light-Running

Reduction in red-light running will improve safety at the intersections. Advance warning provided by the AWEGS system will also significantly benefit truck traffic. Trucks have different braking characteristics compared to cars. Trucks take longer time and a longer distance to stop and hence have different dilemma zones lengths and durations when compared with cars traveling at the same speeds. When trucks are caught in a dilemma zone at the onset of yellow they either enter the intersection in the red or apply a hard brake to stop. Both these maneuvers are unsafe and could result in accidents. So the AWEGS system can significantly improve the safety of the operations at the intersection.

CONCLUSIONS

Based on implementation in two places, AWEGS has shown potential to improve signal operations and safety at high speed signalized intersections. AWEGS works on the principle of predicting the gap out of signal phases based on monitoring the signal status and detector status. AWEGS uses the advance detectors to estimate each individual's travel time to the dilemma zone detectors. AWEGS then monitoring the signal status and the status of all detectors at the intersection predicts the signal controller operation. This methodology allows the signal controller to operate the traffic signal in a fully actuated manner while providing the dilemma zone protection that was designed for the intersection. Sometimes the signal controller does gap out unexpectedly under some circumstances. In such cases, AWEGS system places a phase hold to safely clear any vehicles that may be in the dilemma zone. But data collected illustrated that the AWEGS employed very few phase holds. AWEGS also reduced red-light running by about 40-45 percent.

Since developing AWEGS, researchers at TTI have conducted additional research to further improve the operation and safety of AWEGS. Some of the issues identified during the system development have been overcome and AWEGS is currently ready for implementation. Currently TTI is working with TxDOT for implementation of AWEGS at four sites across the state.

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